ENERGY AND CLIMATE CHANGE RESEARCH AND THE "DARPA MODEL"

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With energy and climate issues increasingly the focus of public policy discussions, the notion that a special research organization—sometimes referred to as ARPA-E—should be created has emerged as one alternative for focusing resources and management attention. More specifically, there have been calls to create a new entity, modeled on the notably successful Defense Advanced Research Projects Agency, DARPA, to perform advanced R&D directed at finding technological solutions to the climate change challenge.[2]

Having spent a fair amount of time looking at DARPA's research program over the years I have been asked what would it take for such an organization to be established and be successful drawing from the historical perspective of the unique organization that it would emulate—DARPA. This will be the focus of my remarks today.

Some key questions we might consider in our discussion are

1. How similar are the type of research tasks of DARPA to those entailed in addressing energy and climate change and how are they different?
2. What are DARPA's key organizational features that have contributed to success and could those features be replicated within the political and

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[2] The DARPA model—sometimes referred to as ARPA-E, or E-ARPA, has been suggested in several venues, most notably in the National Academies' *Rising Above the Gathering Storm, Energizing and Employing America for a Brighter Economic Future*, National Academies, Committee on Science, Engineering, and Public Policy (COSEPUP), 2006,

economic environment surrounding energy and climate change in the executive branch, Congress, and private industry?

3. Are DARPA's 'cultural features' that have been central to its success reproducible under the various possible contemporary arrangements for addressing energy and climate change?

As a former Department of Defense and Department of Energy executive, Dr. John Deutch stated recently,

> Appealing as the DARPA model is, energy and climate-related technology development would present new and different challenges. For example, DARPA does not create for the market – even though technology developed by DARPA has succeeded in the marketplace. Its customer is the Secretary of Defense and ultimately the armed services. Most of the technologies relevant to energy and climate solutions will have private sector customers. This is a problem that DARPA has not had to confront. Still, DARPA offers valuable lessons concerning managing and spurring successful technological innovation. It may be that an imperfect solution to the challenge of technology development still might improve on the record of existing institutions.[3]

Understanding DARPA

We begin this discussion with the following questions

- What is the "DARPA Model", which, as we will explain, raises the question "Which DARPA?"
- What were the origins of DARPA and how did it evolve?
- What have been DARPA's "successes"—why is it so well regarded?
- What is the basic "motif" of DARPA success and what are key factors in achieving success?
- What is relevance of DARPA model for other policy areas—particularly energy and climate research?

The "DARPA Model"

DARPA's primary mission is to foster advanced technologies and systems that create "revolutionary" advantages for the US military. Consistent with this mission, DARPA is independent from the military Services and pursues higher-risk research and development (R&D) projects with the aim of achieving higher-payoff results

[3] John Deutch, "What Should the Government Do To Encourage Technical Change in the Energy Sector?" *MIT Joint Program on the Science and Policy of Global Change*, Report No. 120, *May 2005.*

than those obtained from more incremental R&D. DARPA program managers are encouraged to challenge existing approaches to warfighting and to seek results rather than just explore ideas. Hence, in addition to supporting technology and component development, DARPA has on occasion funded the integration of large-scale “systems of systems” in order to demonstrate what we call today “disruptive capabilities.”

Underlying this “high-risk—high payoff” motif of DARPA is a set of operational and organizational characteristics that Deutch and others have referenced including its relatively small size; its lean, non-bureaucratic structure; its focus on potentially change-state technologies; its highly flexible and adaptive research program. We will return to these characteristics later. **What is important to understand at the outset is that in contrast to the then existing Defense research environment, ARPA was manifestly different.** It did not have labs. It did not focus on existing military requirements. It was separate from any other operational or organizational elements. It was explicitly chartered to be different, so it could do fundamentally different things than had been done by the Military Service R&D organizations.

The reason for this dramatic departure was that President Eisenhower and his key advisors had determined that the existing R&D system had failed to respond to the realities of the emerging national security threat embodied by the Soviet Union. This threat was manifest in a crescendo event—the launching in 1958 of the Sputnik satellite. The response to this not only the creation of a research entity to perform research that others had not adequately pursued, but to embed this organization within a newly created oversight structure reporting to the Secretary of Defense—namely the Director, Defense Research and Engineering, or DDR&E.

DARPA's origins: Strategic Challenges ~1958

ARPA[4] was initially chartered in response to the orbiting of the Sputnik satellite, which raised the specter of the Soviet Union as a technological as well as political threat to the United States. Sputnik itself demonstrated that the USSR not only had ambitions in space, but also had developed the wherewithal to launch missiles with nuclear capabilities to strike the continental United States. Therefore, at the outset ARPA was focused initially on three key areas as Presidential Issues: space, missile defense and nuclear test detection.

- Regarding the first issue, space, soon after its birth a large element of ARPA was spun off to become NASA, based on President Eisenhower's determination that space research should not be directly under the DoD.[5]
- By 1959 ARPA had assignments on ballistic missile defense (DEFENDER) and nuclear test detection (VELA), and also pursued research in solid propellant chemistry, and materials sciences. Soon after ARPA initiated a program on information processing "techniques" with a focus on possible relevance to command and control also began. These became the major elements of ARPA's program over the next decade.
- Soon, based on the initiative of Director of Defense Research and Engineering (DDR&E), John S. Foster, a counterinsurgency program (AGILE) was started as the Vietnam War heated up.

[4] The original name, Advanced Research Projects Agency, ARPA, was changed in 1972 to *Defense* Advanced Research Projects Agency, DARPA. Briefly in 1993-95 the Clinton Administration reverted back to ARPA, but in 1996, the Congress mandated that the name be changed back to DARPA. In historical references I use the name of the organization at that time, either ARPA or DARPA, but for general discussion the current title, DARPA, is used.

[5] Herbert York states it was well understood in ARPA that its broad role in space programs was temporary, with the creation of NASA already in the works both in the White House and in Congress, see Herbert York, *Making Weapons, Talking Peace,* Basic Books, New York, 1987, p. 143.

What is DARPA?

DARPA was first established as a research and development organization immediately under the Secretary of Defense, reporting to the Director of Defense Research and Engineering, then the third highest official in the department with the mission to

- assure that the US maintains a lead in applying state-of-the-art technology for military capabilities

and

- prevent technological surprise from her adversaries.

DARPA's Unique Mission

ARPA was created to fill a unique role, a role which by definition and in its inception put it into contention and competition with the existing Defense R&D establishment. As the *Advanced Research* Projects Agency, ARPA was differentiated from other organizations by an explicit emphasis on "advanced" research, generally implying a degree of risk greater than more usual research endeavors. Former ARPA Director Dr. Eberhardt Rechtin emphasized that research, as opposed to development, implies unknowns, which in turn implies the possibility of failure, in the sense that the advanced concept or idea that is being researched may not be achievable. Were the concept achievable with little or no risk of failure, the project would not be a *research* effort, but a *development* effort.

DARPA over its history has grappled with how to interpret or pursue *advanced* research, both in contrast to the broad array of research being conducted within and for DoD, and relative to its perception of the needs at the time.

Recently DARPA stated its mission as follows:

> DARPA is a Defense Agency with a unique role within DoD. DARPA is not tied to a specific operational mission: DARPA supplies technological options for the entire Department, and is designed to be the "technological engine" for transforming DoD…. a large organization like DoD needs a place like DARPA whose *only* charter is radical innovation. DARPA looks beyond today's known needs and requirements.

It is clear from DARPA's history that within the scope of this mission the emphasis and interpretation of *advanced* research have varied, particularly in terms of (1) the degree and type of risk[6] and (2) how far to go toward demonstration of application. At times with changing circumstances the agency has had to reassess its project mix and emphasis due to determinations both internally and within the Office of the Secretary of Defense regarding the appropriate level of risk and the need to demonstrate application potential. In a sense these somewhat contradictory imperatives serve as the extreme points on a pendulum's swing. As DARPA is pulled toward one of the extremes, often by forces beyond itself, including Congressional pressures, there are countervailing pressures stressing DARPA's unique characteristics to do *militarily relevant advanced research*.

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[6] Risk has several dimensions: (1) lack of knowledge regarding the phenomena or concept itself; (2) lack of knowledge about the applications that might result if the phenomena or concept were understood; (3) inability to gauge the cost of arriving at answers regarding either of these; and (4) difficulty of determining broader operational and cost impacts of adopting the concept. As answers about (1) become clearer through basic research, ideas regarding applications begin to proliferate, as do questions of whether and how to explore their prospects. DARPA is at the forefront of this question and has the difficult job of determining whether enough is known to move toward an application and, if so, how to do so. At times this can be very controversial, as researchers may feel they do not know enough to guarantee success and are concerned that "premature" efforts may in fact create doubts about the utility and feasibility of the area of research, resulting in less funding and (from their perspective) less progress. DARPA, however, has a different imperative than the researcher to strive to see what can be done with the concepts or knowledge, even if it risks exposing what is not known and what its flaws are. This tension is endemic in DARPA's mission and at times has put it at odds with the very research communities that it sponsors.

At the other end of the spectrum, as projects demonstrate application potential, DARPA runs into another set of tensions, not with the researcher, but with the potential recipient of the research product. Given that the ideas pursued are innovative, perhaps revolutionary, they imply unknowns to the user in terms of how they will be implemented and how this implementation will affect their, the implementer's, overall operations. To this end the potential users seek to reduce their uncertainty, in what is a highly risk-intolerant environment, by encouraging DARPA, or some other development agency, to carry forward the concept until these risks are minimized, or simply ignoring, delaying or stretching out its pursuit. While achieving transition can be increased by additional risk reducing research, this also entails substantial additional cost and raises the issue of mission boundaries.

There have been several occasions in DARPA's history when its management has determined that it has done enough in an area to demonstrate the potential of a specific concept—such as Unmanned Air Vehicles (UAVs)—and that it is thus time for others to fund development of its application and acquisition. These decisions have at times resulted in a potential concept becoming a victim of the "valley of death", with the application either failing to be realized, or, as in the case of UAVs, taking over a decade with special high-level attention of OSD to come to fruition. Developing mechanisms to engage potential "customers" in an emerging concept and working with these prospective developers and users as the ideas mature is a key aspect of DARPA project management.

DARPA's Key Characteristics

It was recognized from the outset that DARPA's unique mission required an organization with unique characteristics. Among the most salient of these:

- **It is independent from Service R&D organizations**

DARPA neither supports a Service directly nor does it seek to implement solutions to identified Service requirements. Its purpose is to focus on capabilities that have not been identified in Service R&D and on meeting defense needs that are not

defined explicitly as Service requirements. This does not mean that DARPA does not work with the Services, but it does mean that it does not work the requirements that drive Service R&D.

- **It is a lean, agile organization with risk-taking culture**

DARPA's charter to focus on "high risk; high payoff" research requires that it *be tolerant of failure and open to learning*. It has had to learn to manage risk, not avoid it. Because of its charter, it has adopted organizational, management and personnel policies that encourage individual responsibility and initiative, and a high degree of flexibility in program definition. This is one reason that DARPA does not maintain any of its own labs.

A primary aspect of DARPA's lean structure is that it centers on and facilitates the initiative of its Program Managers. **The DARPA Program Manager is the technical champion who conceives and owns the program**. As the Program Manager is the guiding intelligence behind the program, the most important decisions of DARPA's few Office Directors are the selection of and support of risk-taking, idea-driven Program Managers dedicated to making the technology work.

- **It is idea-driven and outcome-oriented**

The coin of the realm at DARPA is promising ideas. The Project Manager succeeds by convincing others—the Office Director and the DARPA Director—that he or she has identified a high potential new concept. The gating notion isn't that the idea is well-proven, but that it has high prospects of making a difference. The DARPA Program Manager will seek out and fund researchers within US defense contractors, private companies, and universities to bring the incipient concept into fruition. Thus, the research is out-come driven to achieve results toward identified goals, not to pursue science per se. The goals may vary from demonstrating that an idea is technically feasible to providing proof-of-concept for an operational capability. To achieve these results the Program Manager needs to be open to competing approaches, and be adroit and tough-minded in selecting among these.

Which DARPA?

While the concept of DARPA as a “high-risk—high pay-off” organization has been maintained, it also has been an intrinsically malleable and adaptive organization. Indeed DARPA has morphed several times. DARPA has “re-grouped” iteratively—often after its greatest “successes”. The first such occasion was soon after its establishment with the spinning off of its space programs into NASA. This resulted in about half of the then ARPA personnel either leaving to form the new space agency, or returning to a military service organization to pursue military-specific space programs. A few years later then DDR&E John S. Foster required ARPA to transition its second largest inaugural program—the DEFENDER missile defense program—to the Army, much to the consternation of some key managers within ARPA. Also early in its history ARPA was tasked by Foster, acting at the behest of Secretary of Defense McNamara, to conduct a program of applied research in support of the military effort in Viet Nam. At the same time ARPA began what was to become its most famous program—the information technology program that among other things spawned the internet.

More important than the variety of the programs is that they demonstrate the quickness that DARPA took on a new initiative and also how rapidly its programs will move—sometimes more rapidly than its supporters within DARPA desire. However, rather than particular programs or technologies becoming the identifier of what DARPA is, its identity is its rapidly taking on and assessing new ideas and concepts directed at daunting military challenges or overarching application prospects. While the dwell time on new ideas may vary and DARPA may return to the concept iteratively over its history—most notably with its return to missile defense in the 1970s leading to SDI in the 1980s—its hallmark is to explore and create new opportunities, not perfect the ideas that it has fostered.

As an example of its adaptiveness, in the mid-1970s DARPA management in conjunction with the Office of the Secretary of Defense made some crucial decisions on refocusing the organization. With the transitioning of DEFENDER to the Army, ARPA went through a period of exploration and gestation that actually resulted in its budget dropping by 50%. In essence, ARPA management was

looking for the next "big thing"—or in the words of Eberhard Rechtin, the Director at that time, "ARPA had more money than it had ideas". This period of technical exploration led to the incubation of incipient new ideas in sensors—some of which fostered night vision, electronics and information processing, and even weapons concepts—such as terminally guided submunitions. This period of introspection and exploration laid the ground work for a next generation of programs that scaled-up and integrated many of these ideas into major systems concepts—ranging from the internet, to stand-off precision strike weapons, to stealth.[7]

Over the next ten-years DARPA engaged in ambitious and risky scale-up proof-of-concept demonstrations of several of these incipient capabilities, introducing a set of demonstration programs that were radically different than the earlier exploratory technology projects. Over this period DARPA introduced new organizational and management approaches with the explicit purpose to not allow these big demonstrator projects to overwhelm the remaining research agenda, and to drive these demonstrators toward transition and out of DARPA.

Later in its history DARPA was given a range of other roles—some of which might be seen as incongruent to its name, as they were neither defense, advanced research, or even projects. Among these are SEMATECH and the Technology Reinvestment Program (TRP). These and other programs while ancillary and perhaps diversions from DARPA's core focus show how DARPA could quickly adapt and successfully take on such new, temporary excursions—both of which were relatively short-lived. Moreover, even though both of these were substantial undertakings; they did not interfere with DARPA's main mission of exploring highly innovative new concepts.

Thus from this quick synopsis of DARPA's perturbed history should come a conclusion:

There is not and should not be a singular answer on "what is DARPA"—and if someone tells you that—they don't understand DARPA

[7] See Richard Van Atta and Michael Lippitz, *Transformation and Transition: DARPA's Role in fostering an Emerging Revolution in Military Affairs*, IDA Paper P-3698, (Alexandria, VA: Institute for Defense Analyses, March 2003).

DARPA's unique focus is "high risk—high payoff" research. But, clearly this has not been the only focus. Moreover, the content and focus of that research has changed with the circumstances and need. A crucial element of what has made DARPA a special, unique institution is its ability to re-invent itself, to adapt, and to avoid becoming wedded to the last problem it tried to solve.

DARPA roles

While we have emphasized DARPA's adaptability, this is not to say that there aren't some underlying elements to what DARPA does. While there have been some additional ad hoc activities thrown in over time, such as its oversight of SEMATECH, DARPA has had significant roles—with a varying mix—in the following:

- Turning basic science into emerging technologies
- Exploring "disruptive" capabilities (military and more generic)
- Developing technology strategy into a Defense strategy
- Foster revolution or fundamental transformation in a domain of technology application (e.g., the internet or stand-off precision strike)

Key elements of DARPA's success

There are several key elements in DARPA's succeeding in its unique role as an instigator of radical innovation.

- **Create surprise; don't just seek to avoid it**

  DARPA mission is to investigate new emerging technological capabilities that have prospects to create disruptive capabilities. It is differentiated from other R&D organizations by a charter that explicitly emphasizes "high-risk, high payoff" research.

- **Build communities of "change-state advocates"**

  DARPA program managers may often themselves foster a specific concepts or technological approach that they seek to explore and develop. But they almost never are they main, let alone sole, investigator of the notion. Rather it is DARPA's motif to instigate cooperation among a group of forward-looking researchers and operational experts. . In this sense, **DARPA's success depends on it being a leader and catalyst in developing this community of interest.**

- **Define challenges, develop solution concepts, and demonstrate them**

  One aspect of DARPA's success has been efforts to define strategic challenges *in detail*. Since its inaugural Presidential Issues, DARPA has been problem focused, seeking breakthrough, change-state approaches to overcome daunting issues. This has been true in the military realm from the outset. DARPA-sponsored researchers under Project DEFENDER conducted detailed assessments of intercontinental missile phenomena for both defense and offense.[8] Later in the late 1970s, DARPA funded studies to understand how the Warsaw Pact was postured against Western Europe in order to determine how technology could provide a means to offset the Warsaw Pact's numerical and geographic advantages. This planning led to DARPA research in both stealth and stand-off precision strike, which provided the basis for Secretary of Defense Harold Brown's and Director of Defense Research and Engineering William Perry's "Offset Strategy".[9]

  Such detailed conceptual work also facilitated DARPA's non-military research—explicitly that in information technology. JCR Licklider came to DARPA as head of the Information Processing Techniques Office with a vision on man-computer symbiosis that grew in specificity as he collaborated with others, especially Robert Taylor, to present a perspective of internetted computers providing capabilities for collaboration and data interchange amongst researchers.[10] Overtime IPTO grew this initial concept into an increasingly inter-connected strategy.

Tension between DARPA roles

DARPA has been a pursuer of new breakthrough technologies *independent of defined needs*. It also has been a developer of concept prototypes and demonstrations that *address needs* (but not defined requirements). While complementary, these are substantially different roles requiring different management approaches and different types of researchers. The first type of endeavor requires an exploratory, somewhat unstructured approach seeking out alternatives amongst competing ideas. The latter focuses on taking a specific set

[8] For example, in the 1960s and 1970s DARPA funded studies at the then new Institute for Defense Analyses on missile offense and defense first under the STRAT-X project on ICBM offense-defense followed by then PEN-X study which assessed both US and Soviet capabilities to penetrate missile defense systems.

[9] Richard Van Atta and Michael Lipptiz, Transformation and Transition: DARPA's Role in fostering an Emerging Revolution in Military Affairs, IDA Paper P-3698, (Alexandria, VA: Institute for Defense Analyses, March 2003).

[10] JCR Licklider, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Electronics*, volume HFE-1, pages 4–11, March 1960 and JCR Licklider and Robert Taylor, "The Computer as a Communications Devise," *Science and Technology*, April 1968.

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of emerging capabilities and combining them into a demonstration of proof-of-concept. Such demonstrations are generally larger in scale and more resource intensive than exploratory research. Moreover, rather than exploratory, they are aimed at assessing the merit of a specific concept. Indeed, demonstration prototype efforts can be "resources sumps", as they are both uncertain and costly. Therefore the DARPA Director has needs to attentively oversee these while maintaining and protecting the more exploratory research efforts.

DARPA's Successes

Over the nearly fifty years since its inception DARPA has had several major accomplishments that distinguish it as an innovative organization. While these have been recounted elsewhere, it may be useful here to summarize to illustrate the scale, scope, and varying types of innovative capabilities that DARPA helped to instigate.[11]

3rd Generation Info Tech—the Creation of Interactive Information[12]

The singularly most notable technology accomplishment that DARPA is known for is the development of what is now known as modern computing, as embodied in the personal computer and the Internet. While this achievement had its origins in remarkable vision of one man, JCR Licklider, its coming to fruition speaks volumes for the nature of DARPA as an organization and the willingness of its management to support and nurture the pursuit of such an extraordinary perspective.

The vision that Licklider brought to DARPA was one of a totally revolutionary concept of computers and how they could be used. He foresaw that rather than being fundamentally highly automated calculating machines, computers

[11] DARPA's most notable past technical accomplishments have been documented in several prior studies. For an overview of many of DARPA's programs from its inception see Richard Van Atta, et al, *DARPA's Technical Accomplishments*, Volumes I-III, IDA Papers P2192, 1990, P-2429, 1991, and P-2538, 1991. For a more in-depth review of a set of key programs in the 1970s and 1980s that had transformational impact on US military capabilities see Richard Van Atta and Michael Lippitz, et al, *Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs*, IDA Paper P-3698, (Alexandria, VA: Institute for Defense Analyses, March 2003). DARPA's formative role in information technology has been reviewed in detail by Arthur L. Norberg and Judy E. O'Neill. *Transforming Computer Technology: Information Processing for the Pentagon, 1962-1986* (Baltimore, 1996) and M. Mitchell Waldrop, *The Dream Machine: JCR Licklider and the Revolution that Made Computers Personal*, 2002.

[12] M. Mitchell Waldrop. *The Dream Machine*.

could be employed as tools in supporting humans in creative processes.[13] However, to do so would require entirely new, yet non-existent computer capabilities that included the underpinnings for

- interactive computers
- Internetted computing
- Virtual reality
- Intelligent systems

Licklider's extraordinary notion of "man-computer symbiosis" was a fundamental vision that foresaw using new types of computational capabilities to achieve first augmented human capabilities and then possibly artificial intelligence.

He then identified prerequisites that were the underpinnings for this entirely new approach to using computers, which included

- Entirely new types of data-processing equipment and programs that facilitated researchers interacting with *their* computers in real-time.
- Taking advantage of the speed mismatch between the computer, which can perform nearly instantaneously and the slower and more deliberative human. To overcome this mismatch, the computer must divide its time amongst several users [the concept of time-sharing].
- The creation of the "Thinking Center" "a Network of libraries and information storage connected by wideband communications…to individual users"
- Memory and memory organization developed and optimized for search and retrieval
- Entirely different computer language that is "goal oriented" rather than step by step process oriented
- Completely novel input and output mechanisms to overcome the cumbersome punch cards and reams of computer printout with such radical notions as touch-screen displays and even speech recognition

Licklider brought these inchoate notions to DARPA when he was named Director of its Information Processing Techniques Office (IPTO). He brought a powerful vision of what could be and used this as the basis for sustained investment in the underlying technologies to achieve the vision. These investments were aimed at adventurous innovators in academia and in industry—mostly small enterprises on the fringe of the information processing industry then

[13] JCR Licklider, "Man-Computer Symbiosis."

dominated by IBM, such as Bolt, Baranek and Newman (BBN). Moreover, there was an underlying concept of how this investment would lead to applications relying on an entrepreneurial dynamic. This effort became the gestation of a concerted effort that culminated in the ARPANET, as well as a number of technological innovations in the underlying computer graphics, computer processing, and other capabilities that led to **DARPA's fundamental impact on** "**making computers personal"… a truly change-state vision which had fundamental impact in fostering a transformational concept and the creation of an entire industry.**

DARPA's Role in Creating a Revolution in Military Affairs[14]

DARPA has been instrumental in developing a number of technologies, systems and concepts critical to what some have termed the **Revolution in Military Affairs** (RMA) that DoD implemented in the 1990s based on R&D DARPA conducted over the prior fifteen years. It did so by serving as a virtual DoD corporate laboratory: a central research activity, reporting to the top of the organization, with the flexibility to move rapidly into new areas and explore opportunities that held the potential of "changing the business." It was a virtual laboratory because DARPA did not perform research directly but rather acted as a catalyst for innovation by articulating thrust areas linked to overall DoD strategic needs, seeding and coordinating external research communities, and funding large-scale demonstrations of disruptive concepts. In doing so, the DARPA programs presented senior DoD leadership with opportunities to develop disruptive capabilities. When these programs received consistent senior leadership support, typically from the highest levels of the Office of the Secretary of Defense, they transitioned into acquisition and deployment. At other times, without this backing from highest reaches of the department, only the less disruptive, less joint elements moved forward.

[14] This section draws upon Richard Van Atta and Michael Lippitz, et al, *Transformation and Transition: DARPA's Role in fostering an Emerging Revolution in Military Affairs*, IDA Paper P-3698, (Alexandria, VA: Institute for Defense Analyses, March 2003).

An example of one of the most successful DARPA programs is its championing of stealth. While a radical and controversial concept, DARPA's stealth R&D had most of the properties listed above. DARPA harnessed industry ideas. Low-observable aircraft had been built before, for reconnaissance and intelligence purposes, but not pursued for combat applications. The Air Force had little interest in a slow, not very maneuverable plane that could only fly at night. After considerable engineering work, the HAVE BLUE proof-of-concept system enabled top OSD and Service leadership to proceed with confidence to fund and support a full-scale acquisition program. OSD leadership kept the subsequent F-117A program focused on a limited set of high priority missions that existing aircraft could not perform well—e.g., overcoming Soviet integrated air defenses—and worked with Congress to protect its budget, with a target completion date within the same administration. The result was a "secret weapon" capability—exactly what DARPA and top DoD leadership had envisioned.

VISION: DARPA conception, development and demonstration of disruptive capabilities

DARPA's higher-risk, longer-term R&D agenda distinguishes it from other sources of defense R&D funding. ***Perhaps the most important effect of DARPA's work is to change people's minds as to what is possible.*** A fundamental tension for DARPA is balancing its pursuit of high-risk research independent of a defined need with its demonstration of capabilities that address a specific strategic problem (but not defined requirements). Although integration projects may be just as "high risk" as research projects, philosophically, culturally, and managerially, these are very different processes. The DARPA Director needs to mediate between these missions and, more importantly, bridge the two communities. DARPA has been effective in part because a strong axis between DARPA and top OSD leadership formed around ambitious *outcomes*, not technologies per se. An outcome orientation is particularly important in explaining to Congress what DARPA is doing and why.

LEADERSHIP: Acquisition and Deployment of Disruptive Capabilities

DARPA's history shows that *if fielded disruptive capabilities are the objective, it is insufficient for DARPA to create an example and then rely upon the traditional Service acquisition system to recognize its worth and implement it.* Because acquisition and deployment of disruptive capabilities challenge existing programs and bureaucracies, it is difficult to find eager Service customers for them. Also, because new capabilities are not technically mature or operationally robust, the Services will generally be reluctant to take on the significant and potentially costly risk reduction efforts required to move them into acquisition. Hence, rapid acquisition and deployment of disruptive capabilities requires an integrated and consistent senior leadership effort, typically from the Director of Defense Research and Engineering or the Under Secretary of Acquisition, Technology and Logistics. These senior OSD leaders must judiciously exercise their authority to overcome the resistance of people to new ideas, of acquisition organizations to perceived competition, and of requirements and acquisition organizations to uncertainty and risk.

Energy and Climate Change—A DARPA Model?

DARPA's successes in spurring technological innovation have led to numerous calls for applying "the DARPA model" to other issues than national defense. As noted above, one area that has received particular attention is energy technology. Does the DARPA model provide a useful approach to address issues of energy research and development? The foremost question is what is the imperative for radical, transformative R&D in energy technology equivalent to DARPA's national security concern? Are energy security and stemming climate change and its effects comparable motifs?

DARPA is chartered to identify and pursue potential technological capabilities that could provide fundamental advantage to the US relative to existing or potential adversaries. The need to be ahead of all others to "avoid technological surprise" in the interest of national security is a recognized imperative for making exploratory high-risk investments. Do such interests as "energy independence" or

ameliorating climate change provide sufficient imperatives for energy-related advanced research?

DARPA has had the imprimatur of the Secretary of Defense to both engage in highly uncertain R&D not explicitly focused on identified requirements and to promote the application of emergent, often disruptive capabilities based on such research. In essence the Secretary of Defense has played the role of the Chief Executive Officer protecting and supporting the Director of DARPA as the director of innovation—seeking new technological capabilities that can redirect and revitalize an enterprise. While the Department of Energy has pursued advanced S&T in its Office of Science, DOE has not had the type of implementation-focused efforts of advanced technology that have been promoted by DoD leadership in bringing DARPA developments into fruition. While DOE clearly has an important, perhaps dominant role in current energy research, and this research has repercussions for climate change, the two are not synonymous. For example, most of the current energy research agenda is driven by energy efficiency and security concerns focusing on incremental improvements of existing approaches. Also, the scope of climate change R&D goes well beyond the scope of DOE. Evidencing this, the Bush Administration has organized its climate change science and technology efforts via an interagency working group that coordinates a Climate Change Science Program (CCSP) and a Climate Change Technology Program. Each of these programs entails activities of multiple departments and agencies, including DOE, DOC, NASA, DOD, NSF, and the EPA. Moreover, it is debatable whether some major aspects of a climate change focus are within DOE's venue—especially those related to possible measures to combating the effects directly—such as "geoengineering" related to mitigating the effects of atmospheric changes caused by green house gasses. Indeed, such radical notions as dispersing particles in the atmosphere, are the type of high-risk, high payoff research that is most commonly associated with DARPA. Yet, it is not clear whether any individual agency has the responsibility to direct and oversee such research.

Thus, the organizational question for "ARPA-E" is much more problematic than that faced by DARPA. DARPA's job explicitly is national security—and the

main government focus has been the Department of Defense. DARPA has been stretched into broader venues including support for the intelligence community and also the support of more generic commercially-related programs—at one time labeled "dual use" technologies. The intelligence-related aspects of DARPA, while at times collaborated and coordinated with non-DOD interests, particularly the CIA, are clearly linked to the national security mission and the fact that DoD operates its own vast intelligence operations.

This raises another vexing question: How would results of an Energy ARPA be brought into fruition? DARPA has developed an established network of implementation paths that varied by technology and application. It has developed strategies for interacting with military users and developers for bringing military capabilities into application using the support of OSD when needed. It has developed various mechanisms for supporting incipient technological capabilities in universities and small enterprises and provided systematic support that builds an interlinked set of underpinning technologies that together, iteratively have moved closer to an ultimate transformational vision. Can an Energy ARPA obtain the freedom of movement to organize such implementation focused investment strategies? Who would be the organizations that would take the results of ARPA-E's proof-of-concept research and move it into the next level of development? In creating an ARPA-E how clearly defined should be the mechanisms it would draw upon to move its ideas forward? It would be an unfair reading of history to say that all of this was well understood when ARPA was founded. For the military side of the equation the role of the Secretary of Defense and the DDR&E cannot be overstated. Particularly in the 1960s through the 1980s OSD interacted closely with the Director of DARPA in laying out priorities and directions—while the Director was clearly responsible for research.[15]

[15] The interaction between the DARPA director and OSD is important here. This was not a one-way street with OSD handing down specific focus for research, rather it was a dialogue in which the OSD, usually through the DDR&E, today the USD(AT&L), would lay out military and technical challenges it saw as priorities and DARPA would develop its perspective on what emerging technical capabilities might address these. DARPA, often in conjunction with other organizations, such as the Defense Nuclear Agency (DNA), would conduct studies and provide input to high-level DoD leadership on options for addressing daunting strategic concerns.

The path undertaken by DARPA in bringing its technical results into application has been that of a somewhat distant or indirect supporter of the implementation process. In essence DARPA's role in technology transition has been to support technology demonstrations often in conjunction with potential users or through a series of "boot strapped" implementations of new technologies by employing the technology development as inputs to other DARPA research. This latter approach has been particularly effective in the area of information processing technologies, where for example, the DARPA-supported computer workstations were specifically acquired for use by DARPA-funded integrated circuit technology development programs.[16] When the results of the technology development most likely would have to be adopted and adapted by the commercial sector the DARPA approach has generally been one of encouragement, but not direct involvement. The concern that commercialization is a function that is best left to others than those in government has led to proposals for creating alternative, non-governmental mechanisms, such as an Energy Technology Corporation, as suggested by John Deutch.[17]

In employing a DARPA-model to another area of research, it is important to understand that DARPA began as relatively small, highly focused organization that was explicitly taking on problems that were of relatively little priority to existing military R&D organizations. Yet, the issues were of great importance and priority to senior leadership—including the Secretary of Defense and the President. Later, as the policy and technological circumstances changed, DARPA morphed and adapted. In particular, DARPA has been focused on pursuing advanced technology projects that could potentially "make a difference"— and wedded not to the success of any particular project. It has been an "innovation farm" and idea incubator. It has only exceptionally taken on the actual implementation of a technology—and then only as a last resort, or as a very incipient step in application

[16] Van Atta, et al, *DARPA Technical Accomplishments*, Volume II, Chapter XVII, "VLSI : Enabling Technologies for Advanced Computing," Alexandria, VA: Institute for Defense Analyses, April 1991.
[17] John Deutch, "What Should the Government Do To Encourage Technical Change in the Energy Sector?" *MIT Joint Program on the Science and Policy of Global Change*, Report No. 120, *May 2005.*

prototyping. If another department were to stand up an "ARPA-like" organization, it should not try to invent a full-blown, full scale operation based on DARPA after 30 years. Rather, it should endeavor to build the organization organically, adaptively focusing on explicit high priority mission challenges. The idea should not be to make something look like DARPA; it should be to identify and organize advanced research around imperatives that are similar in nature to those that have driven DARPA.

DARPA has been able to take on high-level issues that are disruptive of current operations and technical interests. The example of stealth, above, shows how it fostered a concept that was received hostilely by the main service that was to employ it—the Air Force—and initially rejected by the Navy. Even in its information technology research DARPA confronted a major, well-ensconced vested interest in IBM, who at the time totally dominated not only the computer industry, but also computer research.[18] Can a civilian organization maintain independence of its technology program from such powerful "vested interests"? DARPA had certain advantages that may be difficult to emulate in a non-DoD organization, particularly today. First, at its inception it had the cover of the initial set of Presidential Issues, vested on it directly from the Secretary of Defense. It was given a charter to take on issues that the existing Service R&D structure had failed to give adequate priority to and the results of which were manifestly wanting. As it successfully addressed its initial set of programs it further gained the support of OSD which gave it the top cover it needed. If an Energy ARPA is to have any chance of success it will need this level of support from both the Secretary of Energy and the White House.

[18] See Kenneth Flamm, *Creating the Computer*, Washington, DC: Brookings Institute, 1988, for a discussion of IBM's dominant role in computer research in the early 1960s.

Issues in Establishing an ARPA-E

Some key elements that would need to be addressed, and in some cases directly overcome, if an effective ARPA-E were to be created, are

1. Leadership support – As discussed above, ARPA had President Eisenhower's direct and strong support, and this support has generally been sustained with both the White House and the Secretary of Defense.
2. Congressional oversight – One issue for ARPA-E, relative to DARPA is that DARPA enjoys Congressional oversight that is relatively simple, and has generally had the backing of key members and staffers.
3. Existing Lab structure – ARPA-E will need to contend with a research infrastructure in the National Laboratories, that had no such precedent in DoD. The Service R&D structure lacked the scale and scope of the current "energy labs" and also the support on Capitol Hill that these labs have.
4. Incumbent business interests – DARPA has succeeded by developing and fostering a community of interest ranging from academics to business. It developed these communities piece by piece from the ground up, based on technological capabilities and prospects. It has been able to find within that community interested and innovative participants who were willing to experiment with new ideas. In its information processing technology development, DARPA was able to build an alternative base despite the dominant presence of IBM. It is unclear whether the firms currently in energy production and usage will be open to such experimentation and whether alternative firms and even alternative sectors can grow within the energy industrial structure.

An Energy ARPA has been proposed as a way to respond to critical energy needs by accelerating research in game-changing technologies. Advocates of this new approach need to make a strong case on what it is they see as needing to be done that the current R&D processes are not doing successfully. In essence, they need the moral equivalent of their Sputnik to galvanize support for such a novel agency. Is the lack of a robust hybrid automobile program in the US an example that has similar sway? Is the hydrogen energy effort in this country similar to the ineffective Service response to Soviet ICBMs in the 1950s to provide a stimulus to creating an Energy ARPA? Is the recognition of the anthropogenic climate change impacts reaching a point where high-level policy makers have come to realize that incremental approaches based on existing technologies is so insufficient that a radical enterprise is needed?